



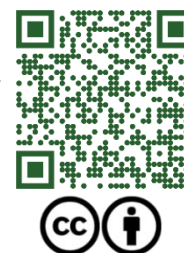
Evaluating Climate-Smart Agricultural Systems: A Comparative Analysis of Policy, Practices, and Impacts in India and New Zealand

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Abstract— Climate-smart agriculture (CSA) has emerged as a critical framework for addressing food security challenges under climate change. This study presents a comparative analysis of CSA systems in India and New Zealand, focusing on policy frameworks, agricultural practices, and socio-economic and environmental impacts. A systematic review of recent literature (2020–2025) was conducted to evaluate implementation outcomes. Results indicate that India prioritizes adaptation strategies and livelihood resilience among smallholder farmers, whereas New Zealand emphasizes greenhouse gas mitigation and precision agriculture. While India faces constraints such as fragmented landholdings and limited access to technology, New Zealand demonstrates strong institutional capacity and innovation-driven systems. The study highlights the need for integrated approaches combining resilience and mitigation strategies for sustainable agricultural development.



Keywords— Climate-smart agriculture, sustainability, adaptation, mitigation, comparative analysis, food security

I. INTRODUCTION

Agriculture is one of the most climate-sensitive sectors, directly affected by rising temperatures, altered precipitation patterns, and increasing frequency of extreme weather events (Kumar et al., 2024; Smith et al., 2020; Thornton and Herrero, 2021). These changes threaten global food security, rural livelihoods, and ecosystem stability, particularly in developing countries where agriculture remains a primary source of income (Maya et al., 2025).

Climate-smart agriculture (CSA) has emerged as a transformative framework to address these challenges by simultaneously enhancing productivity, strengthening resilience, and reducing greenhouse gas (GHG) emissions (Bompotas et al., 2025; Haq et al., 2026; Lipper et al., 2020; Rosenstock et al., 2021; Sharma and Singh, 2025).

CSA is not a single technology but an integrated approach encompassing sustainable land management, efficient

resource use, and climate-resilient innovations. Its implementation varies significantly across regions depending on agroecological conditions, socio-economic factors, and institutional capacity (Kumar et al., 2024; Haq et al., 2026; Pretty and Bharucha, 2021; Sharma and Singh, 2025). While the concept is globally endorsed, its practical application often reflects national priorities and developmental contexts.

India represents a highly vulnerable agrarian economy characterized by smallholder-dominated farming systems, high dependence on monsoon rainfall, and limited access to advanced agricultural technologies (Bithal et al., 2021). Climate variability in India has led to increased incidences of droughts, floods, and yield instability, necessitating the adoption of adaptation-focused CSA strategies (Sharma and Singh, 2025; Shirsath et al., 2020). Government initiatives such as the National Mission for Sustainable Agriculture (NMSA) and the National Innovations in Climate Resilient Agriculture (NICRA) have sought to enhance resilience

through water-use efficiency, soil health management, and climate-resilient crop varieties (Maya et al., 2025).

In contrast, New Zealand presents a technologically advanced agricultural system with strong institutional frameworks and significant global market integration. Agriculture in New Zealand is a major contributor to national greenhouse gas emissions, particularly from livestock production, prompting a strong policy emphasis on mitigation and sustainability (Bompotas et al., 2025; Kumar et al., 2024; Reisinger et al., 2021; Ledgard et al., 2020). The country has adopted innovative approaches such as precision agriculture, low-emission livestock systems, and advanced nutrient management to reduce environmental impacts while maintaining high productivity.

Despite the growing body of literature on CSA, comparative studies examining diverse agroecosystems across developed and developing economies remain limited. Understanding the differences in policy design, technology adoption, and impact outcomes is critical for identifying scalable and context-specific solutions. A comparative analysis between India and New Zealand provides valuable insights into how CSA strategies can be tailored to different socio-economic and environmental conditions.

The specific objectives of this study are:

1. To evaluate CSA-related policy frameworks in India and New Zealand
2. To analyze key climate-smart agricultural practices and their adoption
3. To assess environmental, economic, and social impacts of CSA
4. To identify challenges and opportunities for improving CSA implementation

This study contributes to the existing literature by offering a cross-country comparative perspective, highlighting the interplay between policy, technology, and institutional capacity in shaping CSA outcomes. The findings aim to inform policymakers, researchers, and practitioners in designing more effective and inclusive climate-smart agricultural systems.

II. MATERIALS AND METHODS

2.1 Research Design

This study employs a comparative qualitative research design to evaluate climate-smart agriculture (CSA) systems in India and New Zealand. A comparative approach is particularly suitable for examining differences in policy frameworks, technological adoption, and impact outcomes across diverse agroecological and socio-economic contexts.

The study integrates systematic literature review and thematic analysis, enabling a comprehensive synthesis of existing knowledge on CSA practices and their effectiveness.

2.2 Data Sources

Data were collected from multiple secondary sources (Peer-reviewed journal articles; Scopus-indexed; International reports from organizations such as FAO and World Resources Institute; Government policy documents from India and New Zealand and Research papers on CSA adoption, impacts, and sustainability) to ensure robustness and reliability:

Key databases consulted include Scopus, Web of Science and ScienceDirect. The selection of recent literature ensures that the analysis reflects current trends, technological advancements, and policy developments in CSA.

2.3 Inclusion and Exclusion Criteria

To maintain the quality and relevance of the analysis, the following criteria were applied: The Inclusion Criteria embrace studies published between 2020 and 2025, Peer-reviewed and Scopus-indexed articles, Studies focusing on CSA practices, policies, or impacts and Research specific to India, New Zealand, or comparable agroecosystems. The Exclusion Criteria excludes non-peer-reviewed articles and opinion pieces, Studies lacking empirical or analytical evidence and the Publications prior to 2020 (unless highly relevant foundational works)

2.4 Analytical Framework

The analysis is structured around the three core pillars of CSA:

1. Productivity – improvement in agricultural output
2. Adaptation – resilience to climate variability
3. Mitigation – reduction of greenhouse gas emissions

Each country's agricultural system was evaluated using the following dimensions:

- Policy frameworks
- Agricultural practices
- Environmental impacts
- Economic outcomes
- Social implications

This multidimensional framework allows for a holistic comparison of CSA systems.

2.5 Data Analysis

A thematic synthesis approach was used to analyze qualitative data. Key themes were identified, coded, and compared across the two countries. The analysis focused on:

- Patterns of CSA adoption
- Effectiveness of policy interventions
- Socio-economic and environmental outcomes

Comparative insights were derived by identifying similarities and differences in CSA implementation and outcomes.

2.6 Limitations of the Study

Despite its comprehensive approach, the study has certain limitations such as reliance on secondary data may introduce bias from original sources; Differences in data availability between India and New Zealand and Limited quantitative comparison due to variability in reported indicators. However, the use of multiple high-quality sources and recent literature enhances the reliability and validity of the findings.

III. RESULTS AND DISCUSSION

3.1 Policy Frameworks and Institutional Approaches

Climate-smart agriculture (CSA) policies in India and New Zealand reflect fundamentally different developmental priorities and institutional capacities. In India, CSA is embedded within broader rural development and food security programs such as the National Mission for Sustainable Agriculture (NMSA) and the National Innovations in Climate Resilient Agriculture (NICRA). These initiatives emphasize adaptation, risk reduction, and livelihood security, particularly for smallholder farmers (Bithal et al., 2021; Haq et al., 2026; Shirsath et al., 2020). The policy focus is largely reactive, addressing climate vulnerabilities such as droughts, floods, and soil degradation (Kalisetti et al., 2025; Kumar et al., 2024; Sharma and Singh, 2025).

In contrast, New Zealand adopts a proactive and mitigation-oriented policy framework, integrating agricultural emissions reduction targets into national climate commitments. Policies are strongly supported by scientific research and institutional coordination, enabling precise monitoring and reporting of agricultural greenhouse gas emissions (Ledgard et al., 2020; Reisinger et al., 2021). The presence of well-developed extension systems and data-driven governance enhances the effectiveness of CSA implementation (Maya et al., 2025).

Comparatively, while India demonstrates strong policy intent, challenges remain in implementation due to

fragmented governance and limited access to resources (Aryal et al., 2021; Kumar et al., 2024; Sharma and Singh, 2025). New Zealand's success highlights the importance of institutional coherence, policy integration, and technological infrastructure in achieving CSA objectives.

3.2 Adoption of Climate-Smart Agricultural Practices

The adoption of CSA practices varies significantly between the two countries due to differences in socio-economic conditions, farm size, and technological access.

3.2.1 India

CSA practices in India are primarily **adaptation-driven** and include conservation agriculture, agroforestry, crop diversification, and water-efficient irrigation systems (Jat et al., 2020; Haq et al., 2026; Shirsath et al., 2020). Conservation agriculture, characterized by minimal soil disturbance and residue retention, has been shown to improve soil organic carbon and reduce input costs (Jat et al., 2020). Similarly, agroforestry systems enhance carbon sequestration while providing additional income streams (Kalisetti et al., 2025; Maya et al., 2025; Pretty and Bharucha, 2021).

However, adoption rates remain uneven across regions. Socio-economic barriers such as limited access to credit, lack of technical knowledge, and small landholdings significantly constrain widespread implementation (Aryal et al., 2021; Ma and Rahut, 2024). Studies indicate that farmer awareness and institutional support are critical determinants of CSA adoption in developing countries (Roy et al., 2025; Rosenstock et al., 2021; Sharma and Singh, 2025).

3.2.2 New Zealand

In New Zealand, CSA practices are **technology-intensive and mitigation-focused**, including precision agriculture, digital farming, and low-emission livestock management systems (Ledgard et al., 2020; Reisinger et al., 2021). Precision agriculture enables optimized use of inputs such as fertilizers and water, reducing environmental impacts while maintaining high productivity.

Livestock systems, which contribute significantly to national emissions, are being transformed through improved feed efficiency, methane inhibitors, and advanced breeding techniques (Ledgard et al., 2020). Additionally, climate forecasting and decision-support tools allow farmers to proactively manage climate risks.

Overall, New Zealand exhibits higher adoption rates due to better access to capital, advanced research infrastructure, and strong policy support (Figure 1).

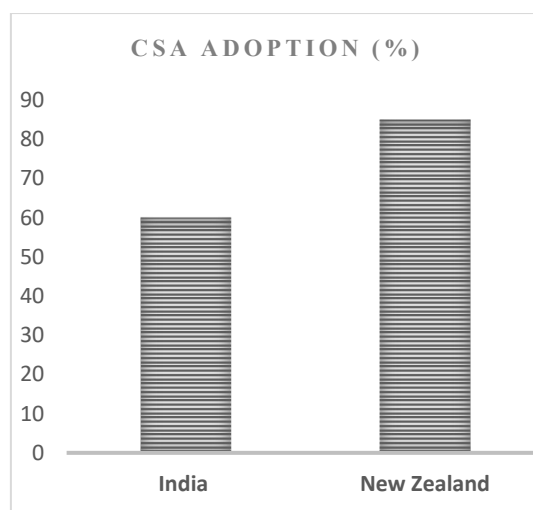


Fig 1: Comparative adoption levels of climate-smart agriculture practices in India and New Zealand, indicating higher technological uptake in New Zealand.

3.3 Environmental Impacts

CSA practices contribute significantly to environmental sustainability in both countries, although the nature and scale of impacts differ.

In India, CSA interventions have been shown to: Enhance soil fertility and organic carbon content; Improve water-use efficiency and Reduce land degradation (Jat et al., 2020; Shirsath et al., 2020; Roy et al., 2025; Zhao et al., 2023)

However, mitigation outcomes remain limited due to the dominance of small-scale farming and low mechanization levels (Sharma and Singh, 2025; Smith et al., 2020). The primary environmental benefit lies in adaptation and resilience building rather than emission reduction.

In contrast, New Zealand demonstrates strong performance in GHG mitigation, particularly in reducing methane and nitrous oxide emissions from livestock systems (Reisinger et al., 2021). Advanced nutrient management systems also minimize nitrogen leaching and water pollution (Ledgard et al., 2020; Haq et al., 2026).

Despite these achievements, challenges persist in balancing productivity with environmental sustainability, particularly in intensive dairy farming systems.

3.4 Economic Impacts

CSA adoption has significant economic implications for farmers in both countries. In India, CSA practices contribute to increased crop yields, reduced input costs and improved income stability (Aryal et al., 2021; Ma and Rahut, 2024; Zhao et al., 2023). However, initial investment costs and risk aversion among farmers can limit adoption. Economic benefits are often realized in the long term, making policy support and financial incentives crucial.

In New Zealand, economic impacts are more pronounced due to high productivity levels, efficient resource utilization and strong market integration. CSA practices enhance export competitiveness while ensuring compliance with environmental regulations. The integration of technology reduces operational costs and increases profitability.

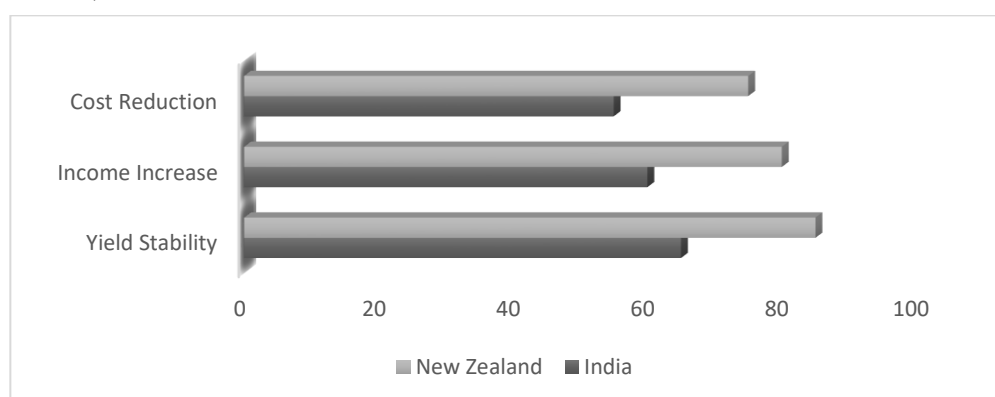


Fig 2: Comparative economic benefits of climate-smart agriculture practices, showing higher performance indicators in New Zealand relative to India.

3.5 Social Impacts and Livelihood Resilience

CSA plays a critical role in enhancing social resilience and food security. In India, CSA contributes to improved livelihood security for smallholder farmers, reduced vulnerability to climate shocks and enhanced food security (FAO et al., 2023; Roy et al., 2025). However, social inequalities, including gender disparities and unequal access to resources, remain significant challenges.

In New Zealand, social impacts are linked to improved farmer awareness and education, strong institutional support systems and community-based sustainability initiatives. The emphasis is less on survival and more on sustainable intensification and environmental stewardship.

3.6 Integrated Comparative Insights

The comparative evaluation reveals three key insights:

1. *Adaptation vs Mitigation Divide*
India prioritizes adaptation due to high climate vulnerability, while New Zealand emphasizes mitigation aligned with global climate commitments (Lipper et al., 2020; Smith et al., 2020; Roy et al., 2025).

2. *Role of Technology and Institutions*
Technological advancement and institutional capacity are critical drivers of CSA success. New Zealand's integrated systems outperform India's fragmented implementation (Reisinger et al., 2021).
3. *Scalability and Inclusivity Challenges*
India's challenge lies in scaling CSA across millions of smallholders, whereas New Zealand must address emissions from intensive livestock systems.

3.7 Synthesis

The findings suggest that an integrated CSA framework combining India's resilience-focused strategies with New Zealand's mitigation-driven innovations can significantly enhance global agricultural sustainability. Strengthening policy coherence, improving access to technology, and promoting farmer participation are essential for scaling CSA effectively (Pretty and Bharucha, 2021; Rosenstock et al., 2021; Roy et al., 2025; Sharma and Singh, 2025).



Fig 3: Comparative framework of climate-smart agriculture (CSA) systems in India and New Zealand, illustrating the integration of adaptation-focused smallholder resilience in India and mitigation-driven technological innovations in New Zealand within the three core CSA pillars—productivity, adaptation, and mitigation.

IV. CHALLENGES

The implementation of climate-smart agriculture (CSA) in India and New Zealand is constrained by a range of socio-economic, technological, and institutional challenges, reflecting their distinct agricultural contexts.

4.1 Challenges in India

4.1.1 Structural and Socio-economic Constraints

Agriculture in India is dominated by small and marginal farmers, often operating on fragmented landholdings. This

limits economies of scale and restricts the adoption of advanced CSA technologies (Birthal et al., 2021). Financial constraints, including limited access to credit and insurance, further hinder investment in climate-resilient practices (Aryal et al., 2021).

4.1.2 Knowledge and Institutional Gaps

A major barrier to CSA adoption is the lack of awareness and technical knowledge among farmers. Extension services remain underdeveloped, leading to inadequate dissemination of CSA practices (Rosenstock et al., 2021).

Additionally, policy implementation is often fragmented across multiple institutions, reducing overall effectiveness.

4.1.3 Technological Limitations

Access to modern technologies such as precision agriculture, climate forecasting tools, and digital advisory systems remains limited, particularly in rural areas. This digital divide restricts the scalability of CSA interventions (Ma and Rahut, 2024; Roy et al., 2025; Sharma and Singh, 2025).

4.1.4 Climate Vulnerability

India's high exposure to climate risks, including droughts, floods, and heatwaves, exacerbates agricultural uncertainty. These conditions necessitate continuous adaptation, making long-term planning challenging (Shirsath et al., 2020; Sharma and Singh, 2025).

4.2 Challenges in New Zealand

4.2.1 Livestock-Related Emissions

Agriculture in New Zealand is a significant source of greenhouse gas emissions, particularly methane from ruminant livestock. Reducing these emissions without compromising productivity remains a key challenge (Reisinger et al., 2021; Ledgard et al., 2020).

4.2.2 Trade-offs Between Productivity and Sustainability

Efforts to reduce environmental impacts may conflict with the goal of maintaining high agricultural output and export competitiveness. Balancing these competing objectives requires innovative solutions and policy support.

4.2.3 Policy and Market Pressures

Stringent environmental regulations and international market expectations place additional pressure on farmers to adopt sustainable practices. Compliance costs may be high, particularly for smaller farming enterprises.

4.2.4 Technological and Behavioral Barriers

While technological solutions are available, their adoption depends on farmer willingness, awareness, and cost considerations. Behavioral resistance to change can slow down the transition to low-emission farming systems (Tsoumas et al., 2022).

4.3 Cross-Cutting Challenges

Both India and New Zealand face common challenges, including:

- Uncertainty in climate projections
- Need for improved data and monitoring systems
- Integration of policies across sectors
- Ensuring equitable access to CSA technologies

Addressing these challenges requires coordinated policy efforts, technological innovation, and stakeholder engagement (Pretty and Bharucha, 2021; Roy et al., 2025).

V. FUTURE PROSPECTS

The future of climate-smart agriculture lies in integrating technological innovation, policy coherence, and inclusive development strategies. Both countries present unique opportunities for advancing CSA at national and global levels.

5.1 Technological Innovations

Emerging technologies such as artificial intelligence, remote sensing, and precision agriculture have the potential to revolutionize CSA. In New Zealand, these technologies are already being integrated into farming systems, enhancing efficiency and reducing environmental impacts (Ledgard et al., 2020).

In India, expanding access to digital agriculture platforms, mobile-based advisory services, and climate forecasting tools can significantly improve CSA adoption and effectiveness (Ma and Rahut, 2024; Roy et al., 2025).

5.2 Policy Integration and Institutional Strengthening

Future CSA strategies must focus on policy coherence and institutional coordination. Aligning agricultural, environmental, and climate policies can enhance implementation efficiency. Strengthening extension services and farmer training programs is particularly critical in India.

New Zealand can further refine its policies by integrating economic incentives with environmental goals, promoting sustainable intensification.

5.3 Climate Finance and Investment

Access to climate finance is essential for scaling CSA. In India, targeted subsidies, credit schemes, and insurance programs can support smallholder farmers in adopting climate-resilient practices (Aryal et al., 2021; Godwin, and Mwebaze.,2025).

International funding mechanisms and public-private partnerships can play a key role in promoting CSA globally.

5.4 Knowledge Sharing and International Collaboration

Collaboration between developed and developing countries can facilitate the exchange of knowledge, technologies, and best practices. Lessons from New Zealand's mitigation strategies can inform India's policies, while India's large-scale adaptation approaches can provide insights for other vulnerable regions. (Tsoumas et al., 2022).

5.5 Sustainable Intensification and Food Systems Transformation

CSA must evolve towards sustainable intensification, ensuring increased productivity without environmental degradation (Pretty and Bharucha, 2021; Roy et al., 2025; Zhao et al., 2023). This includes efficient resource use, reduced emissions and enhanced ecosystem services. Transforming food systems to be more resilient, inclusive, and sustainable is essential for achieving global climate and development goals (Godwin, and Mwebaze.,2025; Tsoumas et al., 2022).

VI. CONCLUSION

Climate-smart agriculture represents a comprehensive and adaptive framework for addressing the complex challenges posed by climate change to agricultural systems. This study provides a comparative analysis of CSA in India and New Zealand, highlighting significant differences in policy priorities, technological adoption, and impact outcomes.

The findings reveal that India's CSA approach is largely adaptation-oriented, focusing on enhancing resilience among smallholder farmers and ensuring food security under climate stress. In contrast, New Zealand emphasizes mitigation and technological innovation, driven by strong institutional frameworks and advanced research systems.

Despite these differences, both countries demonstrate the potential of CSA to improve agricultural sustainability, reduce environmental impacts, and enhance economic outcomes. However, challenges such as resource constraints, technological gaps, and policy fragmentation in India, and emission reduction pressures in New Zealand, highlight the need for targeted interventions.

A key contribution of this study is the identification of a hybrid CSA model, integrating:

- India's strengths in resilience and adaptation
- New Zealand's advancements in mitigation and technology

Such an integrated approach can significantly enhance global agricultural sustainability and climate resilience. Future efforts should focus on strengthening policy coherence, promoting technological innovation, and ensuring inclusive participation of farmers.

Ultimately, achieving the goals of climate-smart agriculture requires a multi-dimensional and collaborative approach, involving governments, researchers, private sector stakeholders, and farming communities. The insights from this comparative analysis provide a foundation for designing more effective CSA strategies that can contribute to sustainable food systems and climate change mitigation at a global scale.

VII. HIGHLIGHTS

- Comparative evaluation of climate-smart agriculture (CSA) systems in India and New Zealand
- India emphasizes adaptation and smallholder resilience
- New Zealand focuses on mitigation and technological innovation
- Institutional capacity and policy frameworks drive CSA adoption
- Cross-learning enhances global sustainability outcomes

DECLARATION REGARDING CONFLICT OF INTEREST

The author declares no conflict of interest. Disha Chahal conceptualized, analyzed the literature, and wrote the manuscript. The ethics approval is not applicable.

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